US009250273B2

(12) **United States Patent**
Nagao

(10) **Patent No.:** **US 9,250,273 B2**
(45) **Date of Patent:** **Feb. 2, 2016**

(54) **CURRENT SENSOR**

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(72) Inventor: **Naoyuki Nagao**, Tokyo (JP)

(73) Assignee: **FUJITSU COMPONENT LIMITED**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 244 days.

(21) Appl. No.: **13/933,796**

(22) Filed: **Jul. 2, 2013**

(65) **Prior Publication Data**

US 2014/0077797 A1 Mar. 20, 2014

(30) **Foreign Application Priority Data**

Sep. 20, 2012 (JP) 2012-206661

(51) **Int. Cl.**

G01R 33/04	(2006.01)
G01R 15/20	(2006.01)
G01R 19/15	(2006.01)
G01R 19/00	(2006.01)
G01R 1/20	(2006.01)
G01R 33/07	(2006.01)

(52) **U.S. Cl.**

CPC ***G01R 19/15*** (2013.01); ***G01R 1/203*** (2013.01); ***G01R 15/202*** (2013.01); ***G01R 15/207*** (2013.01); ***G01R 19/0092*** (2013.01); *G01R 19/00* (2013.01)

(58) **Field of Classification Search**

CPC G01R 33/02; G01R 15/202; G01R 33/07; G01R 33/18; G01R 19/0092; G01R 1/203; G01R 15/207; G01R 19/00

USPC .... 324/117 H, 117 R, 126, 127, 156, 157, 324/227, 228, 236, 244, 253

See application file for complete search history.

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Assistant Examiner — Raul Rios Russon
(74) *Attorney, Agent, or Firm* — Staas & Halsey LLP

(57) **ABSTRACT**

A current sensor includes: a current bar through which a current flows; a first cover that covers the current bar and includes a cutout portion formed in at least a part thereof; a magnetic substance core that covers at least parts of the current bar and the first cover and includes a gap; a magnetic field measuring element located in the gap; and a second cover that covers the magnetic substance core and the magnetic field measuring element and at least parts of the current bar and the first cover, and is located so that a side surface thereof engages with the cutout portion of the first cover.

13 Claims, 25 Drawing Sheets

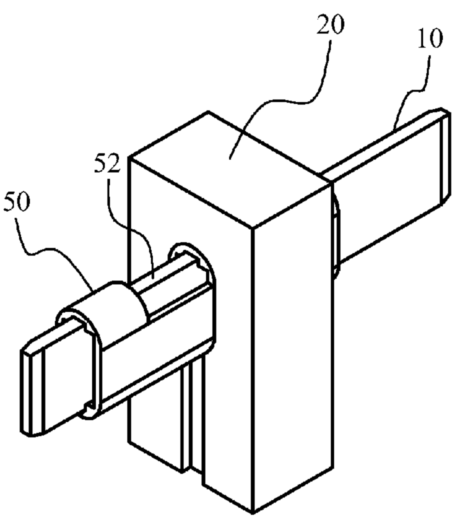

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FIG. 1A

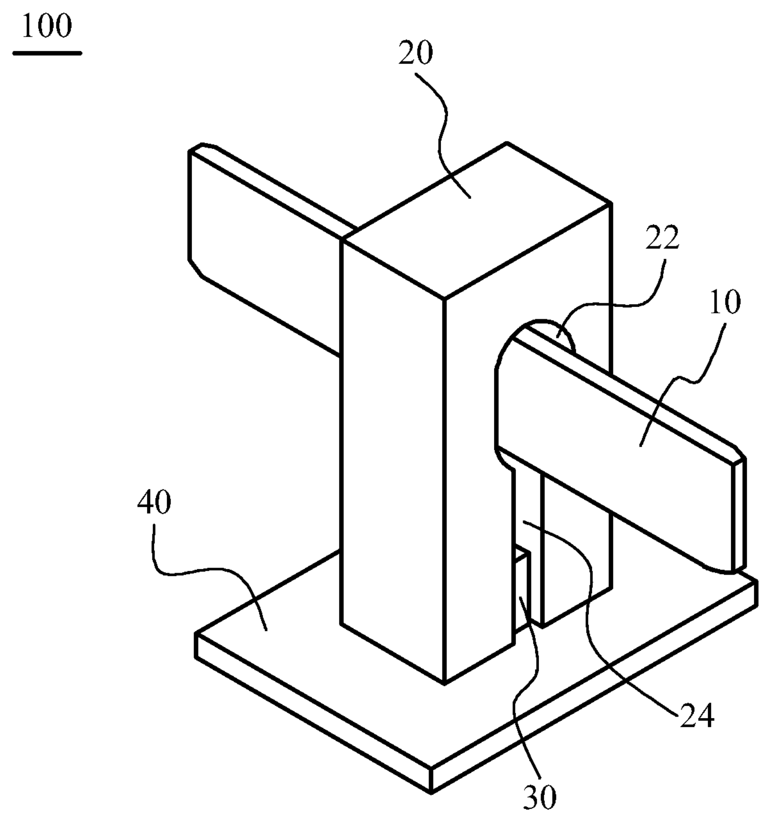


FIG. 1B

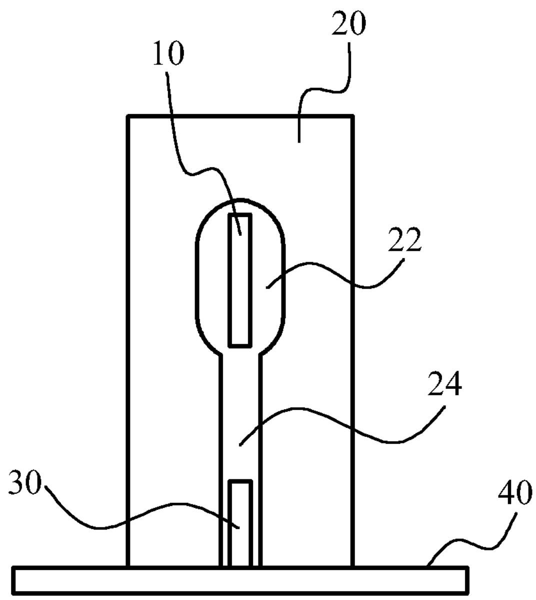
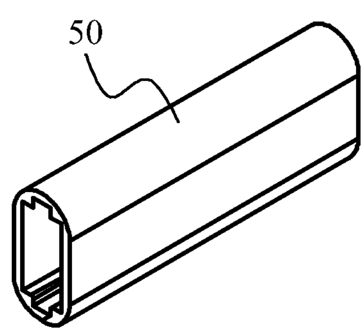


FIG. 2A



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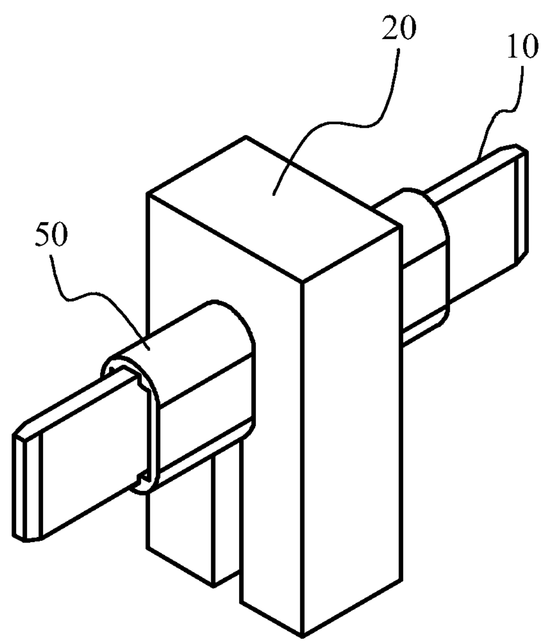


FIG. 3A

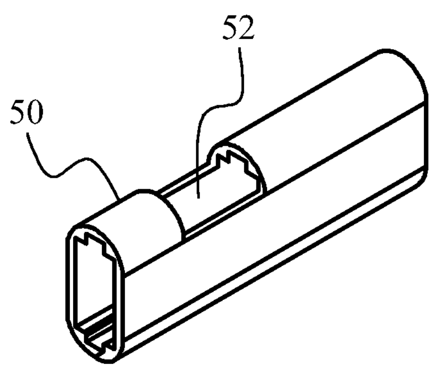


FIG. 3B

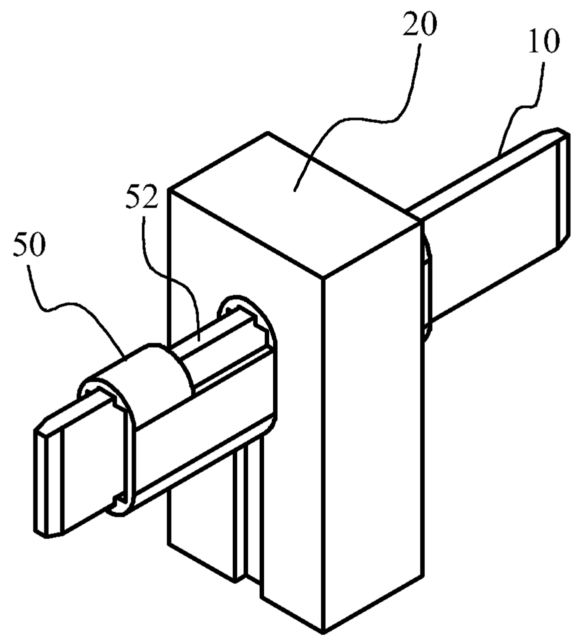


FIG. 4A

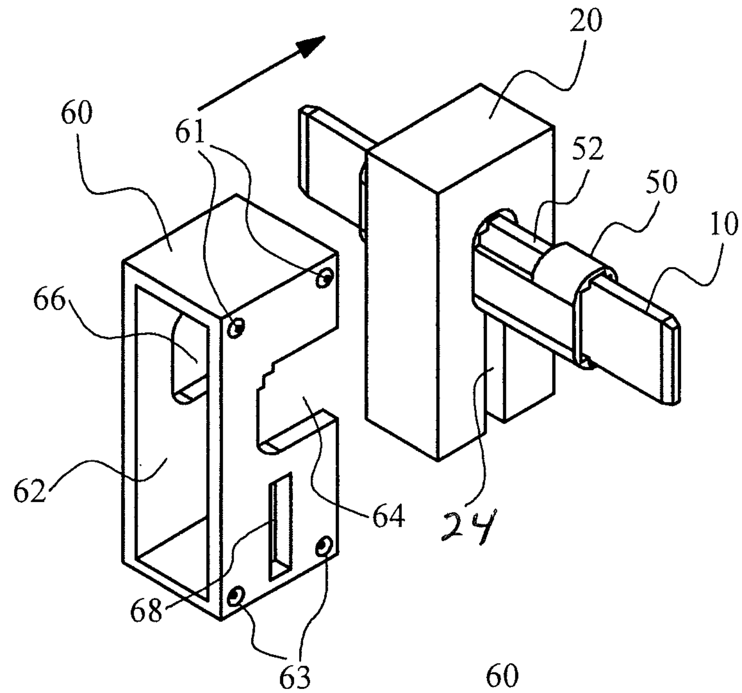


FIG. 4B

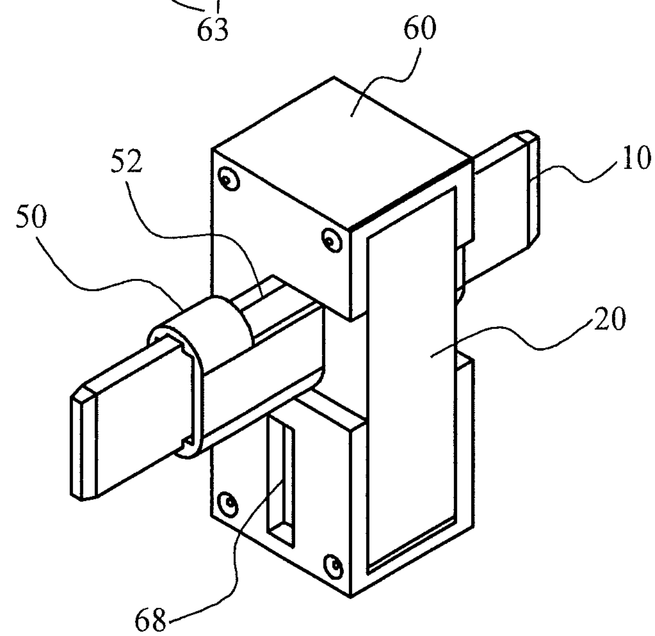
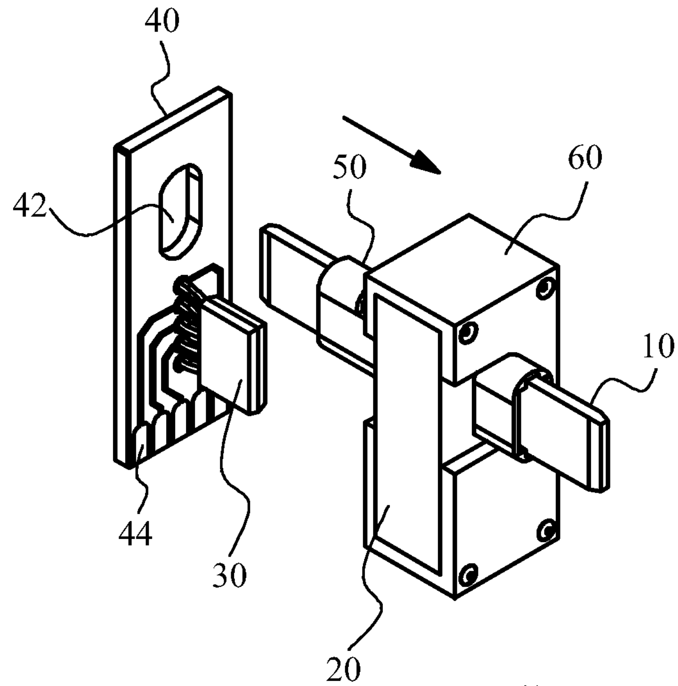


FIG. 5A



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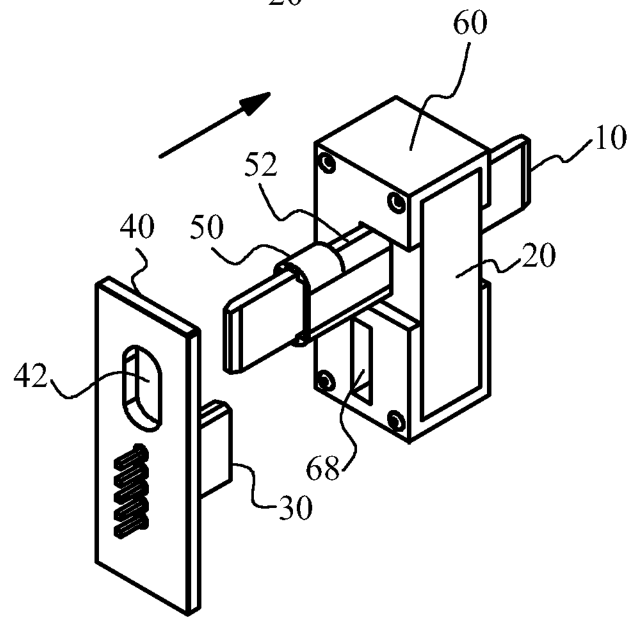
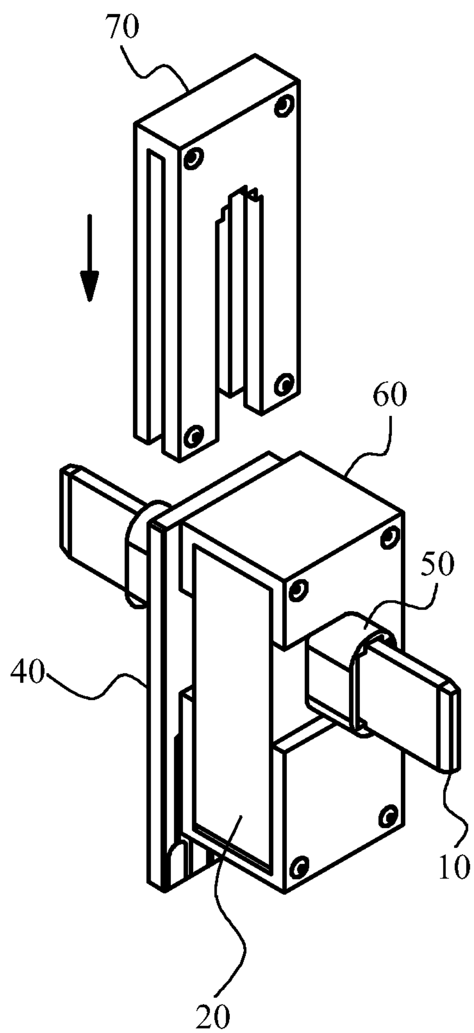


FIG. 6A



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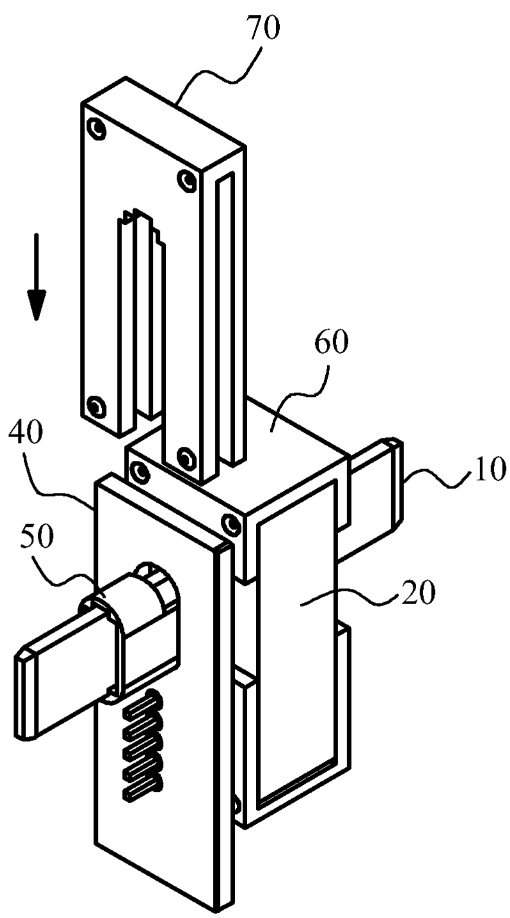

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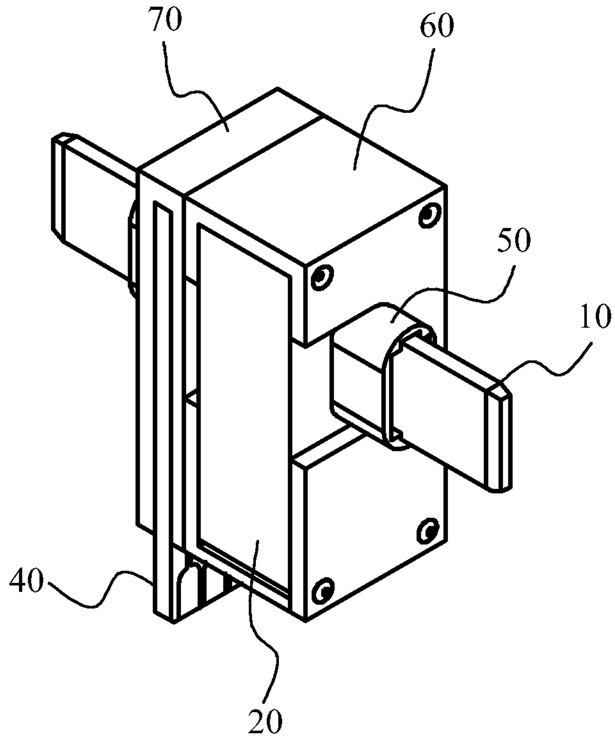


FIG. 7B

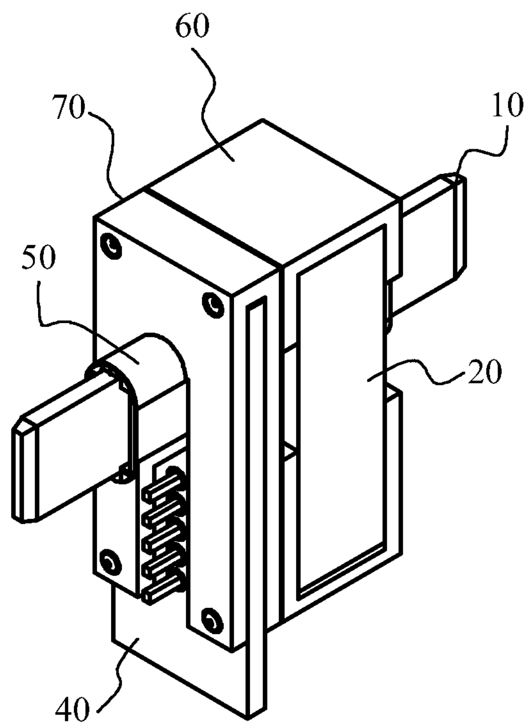


FIG. 8A

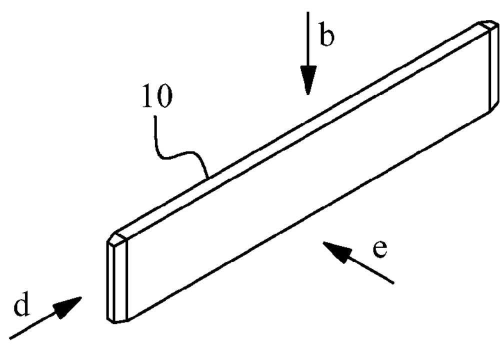


FIG. 8B

FIG. 8C

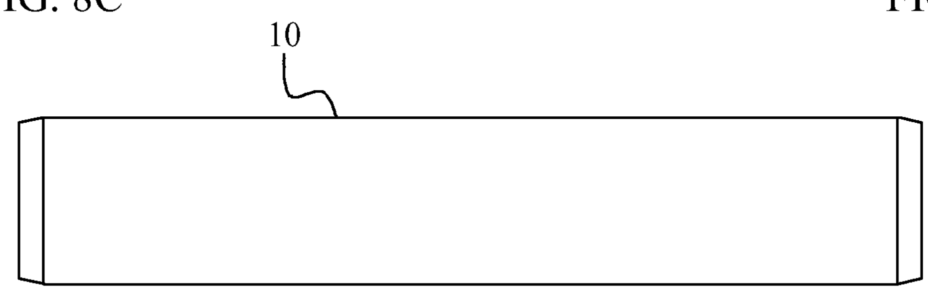


FIG. 8D

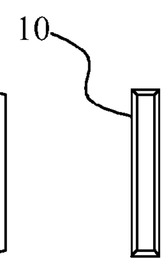
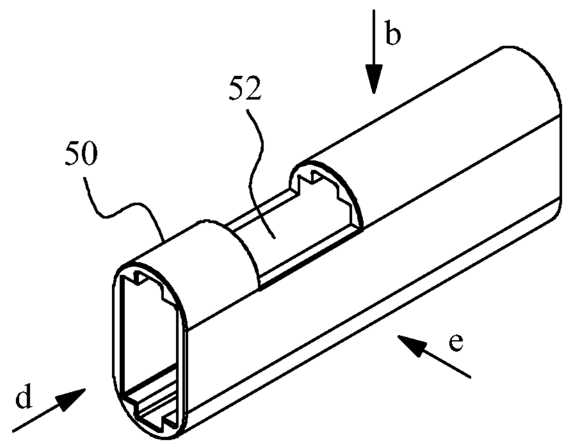


FIG. 9A



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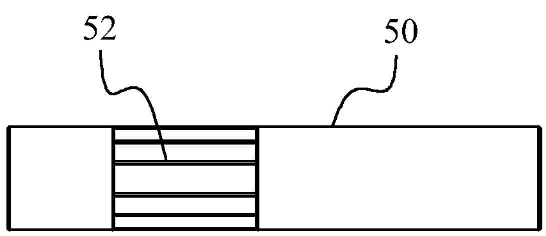
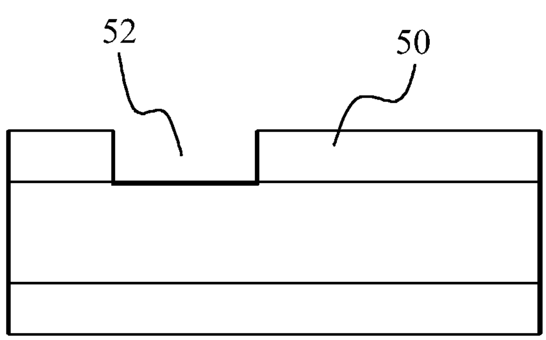


FIG. 9C



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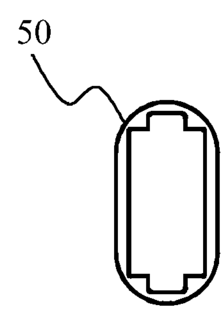


FIG. 10A

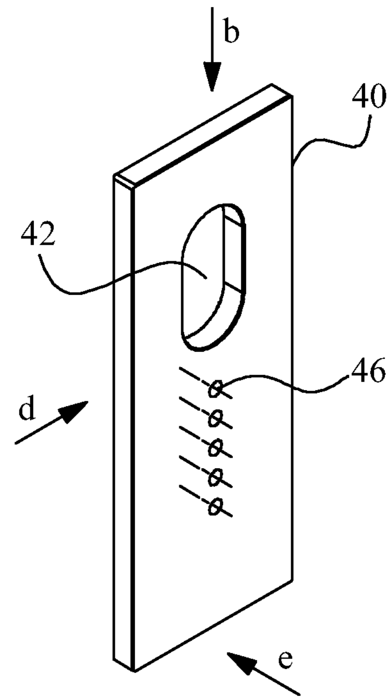
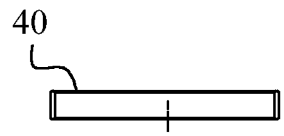


FIG. 10B



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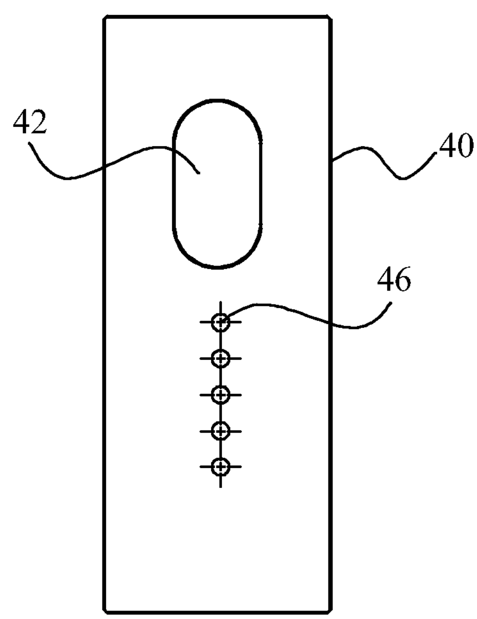

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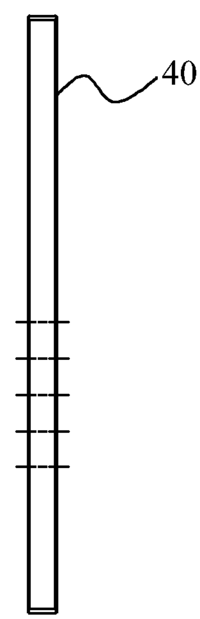


FIG. 11A

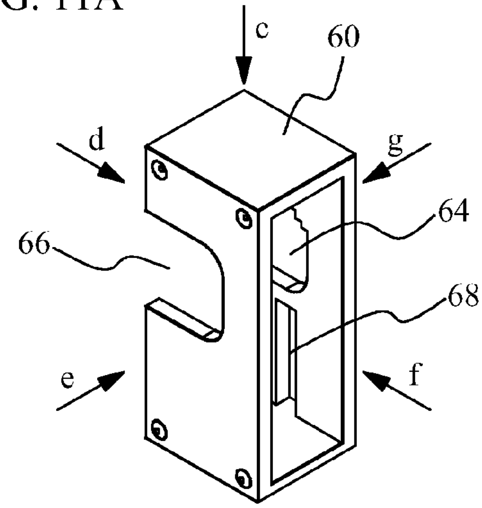


FIG. 11B

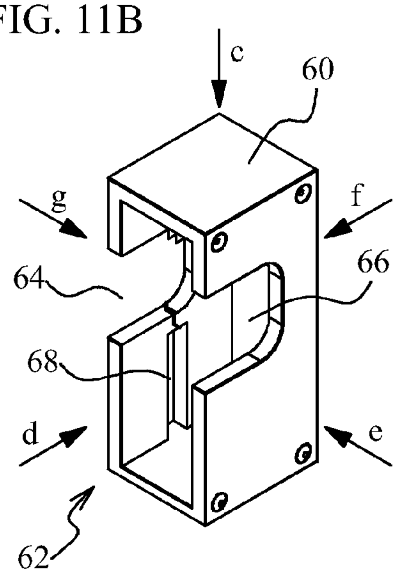


FIG. 11C

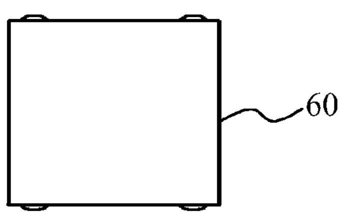


FIG. 11D

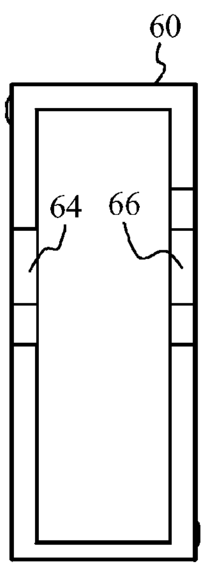


FIG. 11E

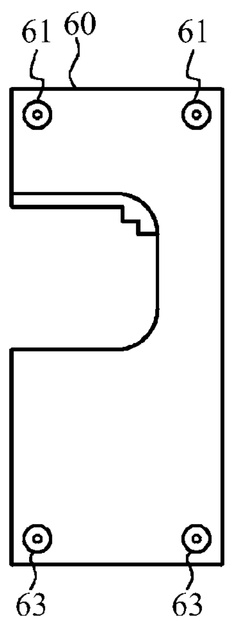


FIG. 11F

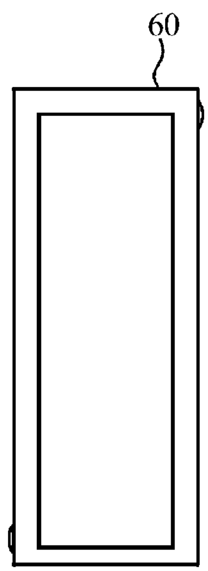


FIG. 11G

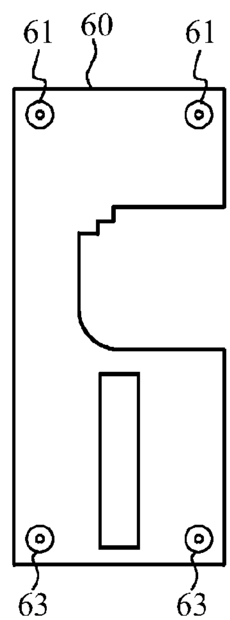


FIG. 12A

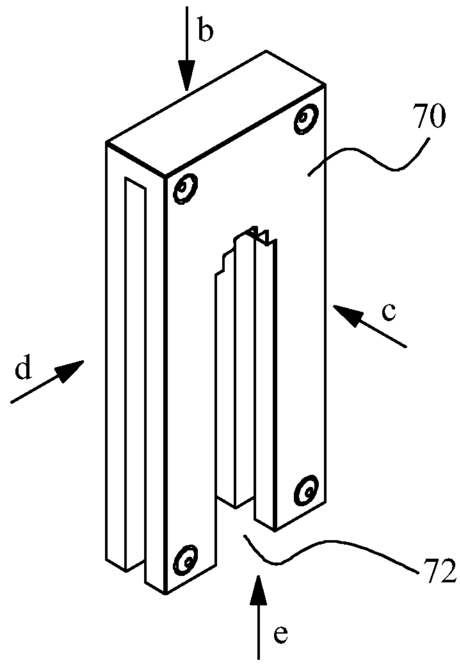
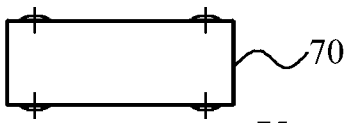


FIG. 12B



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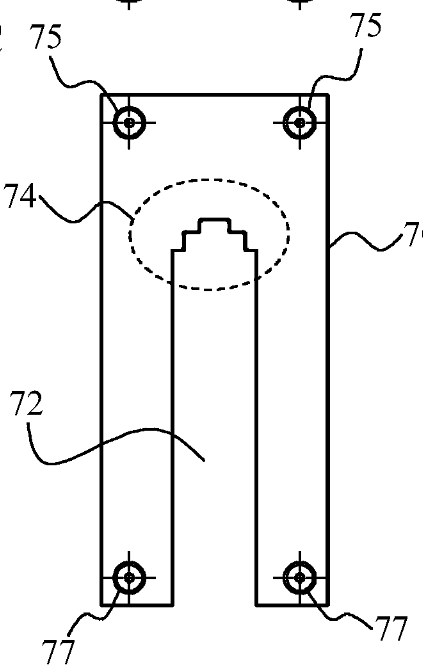

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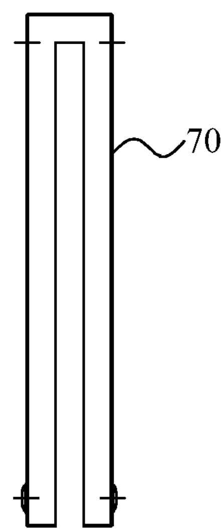

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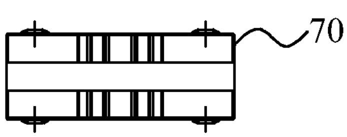


FIG. 13A

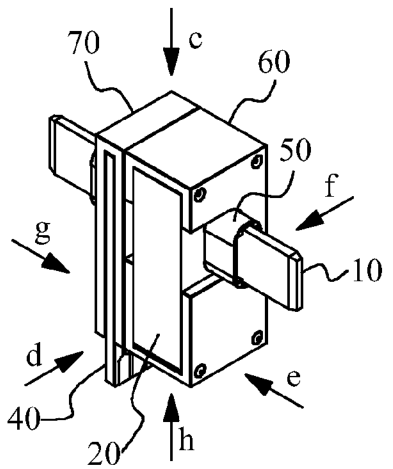
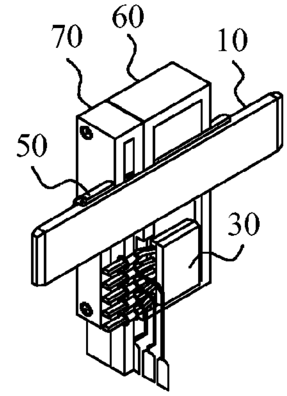


FIG. 13B



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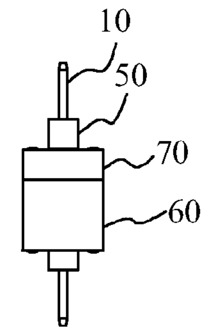


FIG. 13D

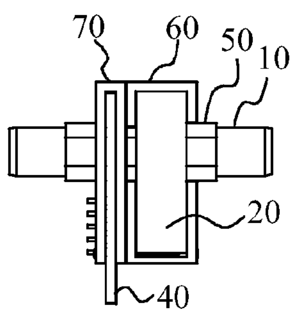


FIG. 13E

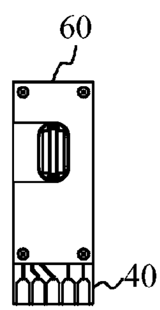


FIG. 13F

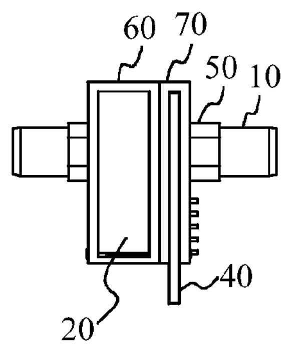


FIG. 13G

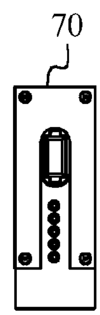


FIG. 13H

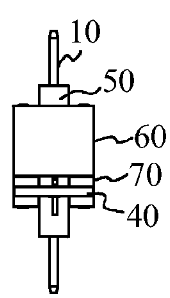
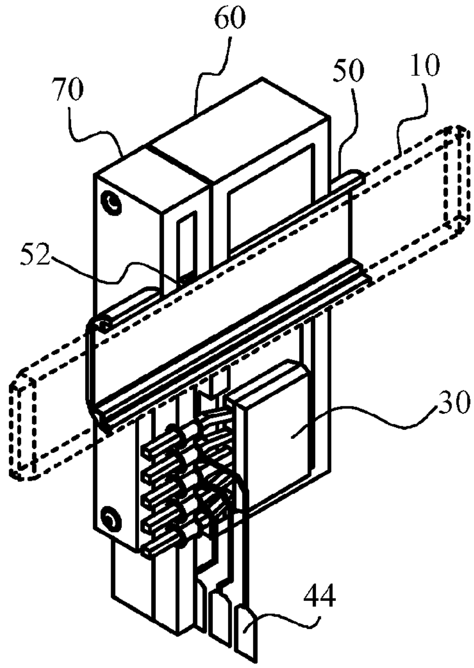


FIG. 14A



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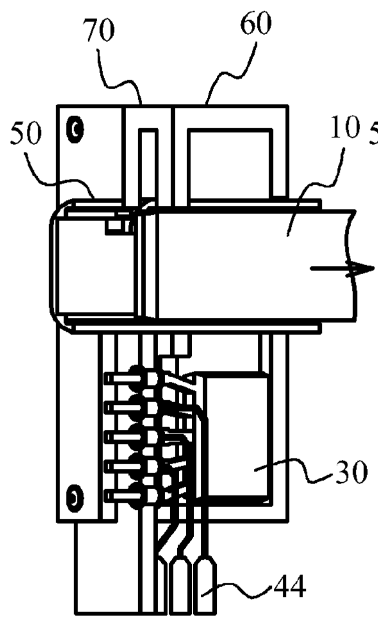

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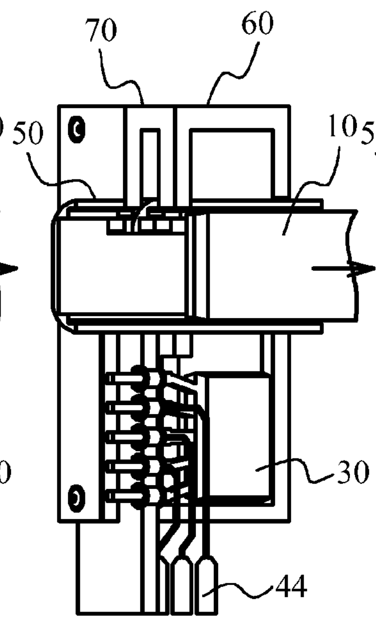

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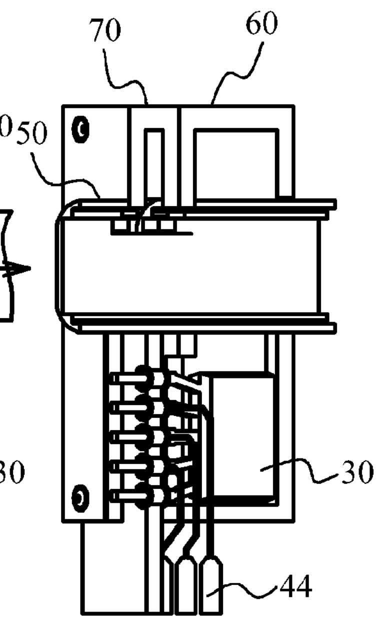


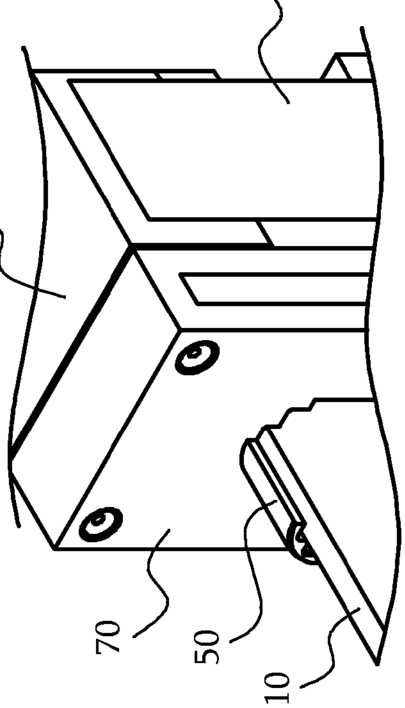


FIG. 15A

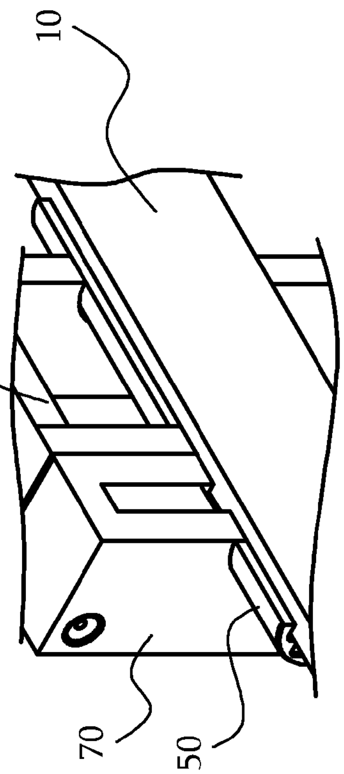
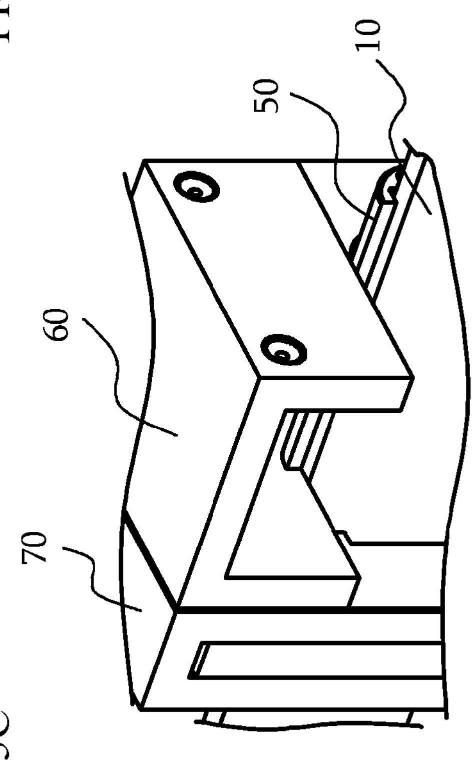


FIG. 15B



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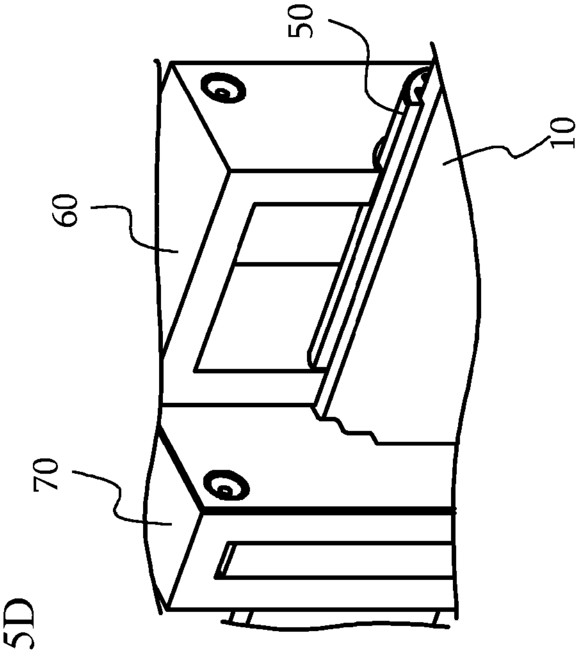


FIG. 15D

FIG. 16A

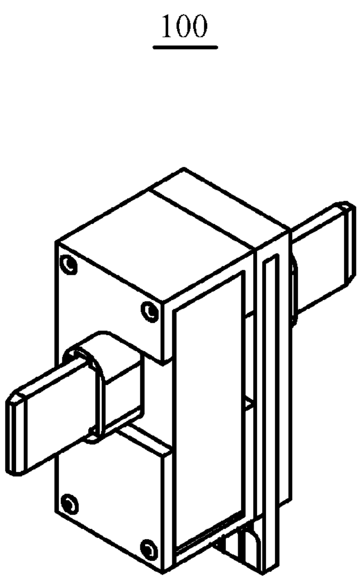


FIG. 16B

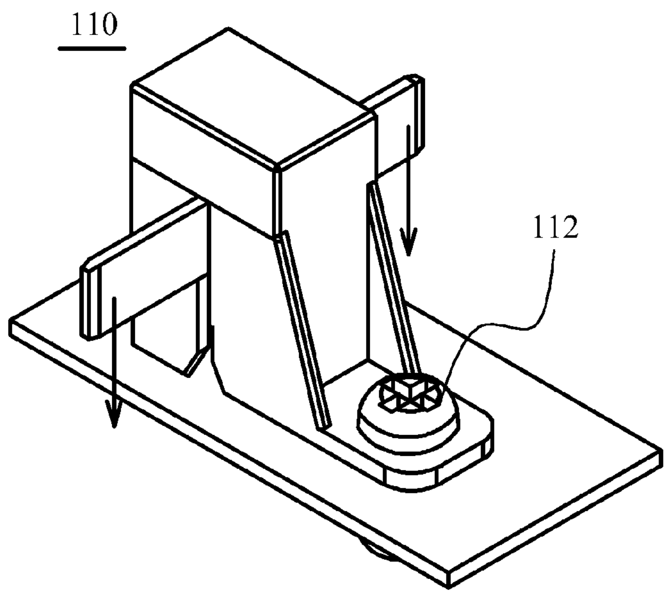


FIG. 17A

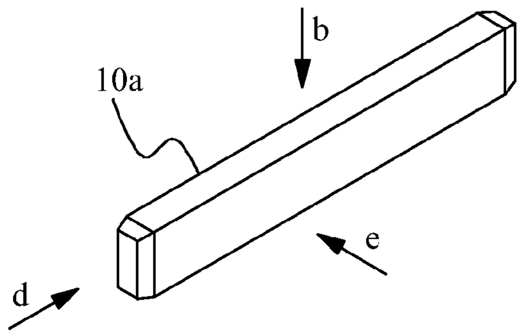


FIG. 17B

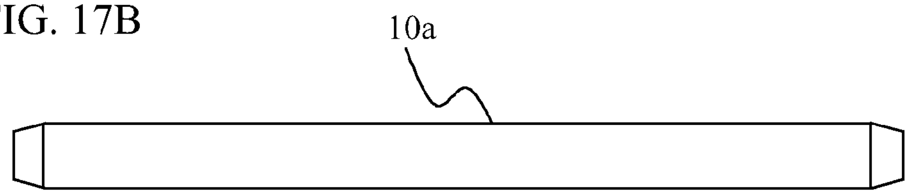


FIG. 17C

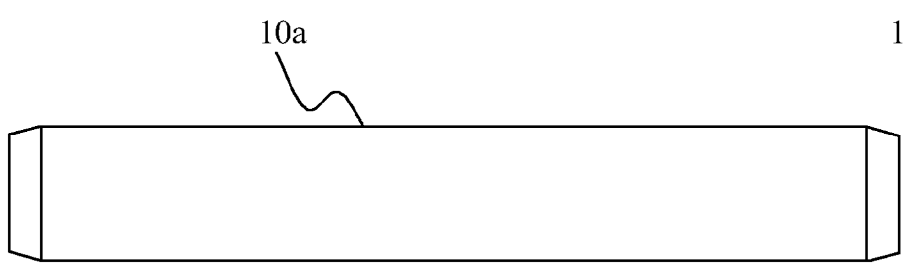


FIG. 17D

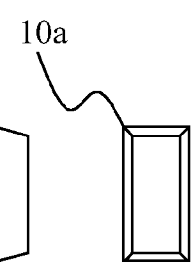


FIG. 18A

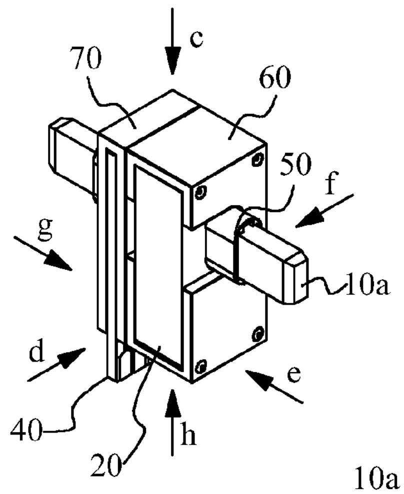


FIG. 18B

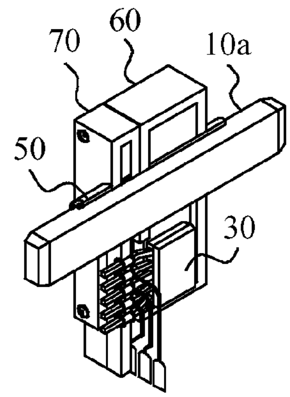


FIG. 18C

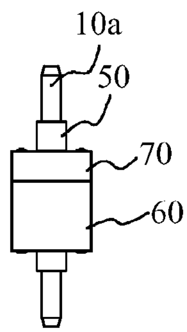


FIG. 18D

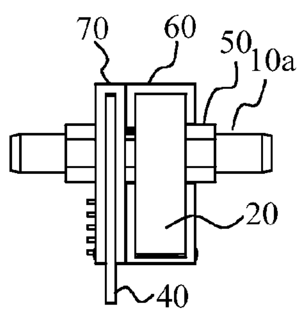


FIG. 18E

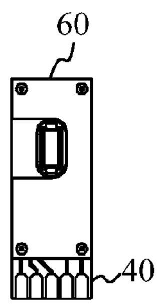


FIG. 18F

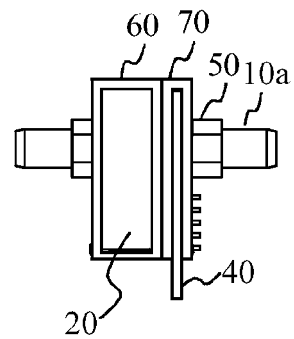


FIG. 18G

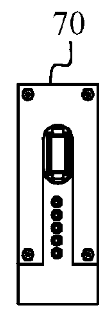


FIG. 18H

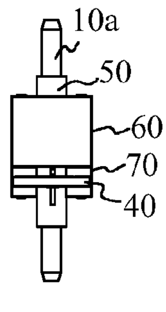


FIG. 19A

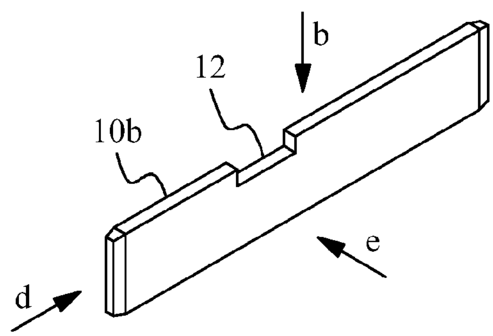


FIG. 19B

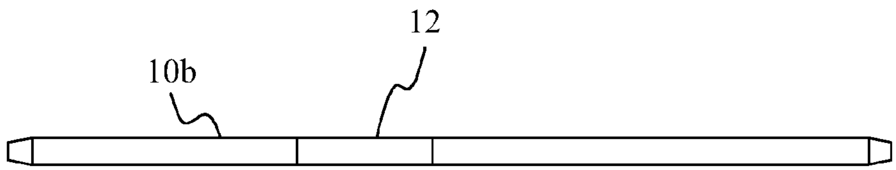


FIG. 19C

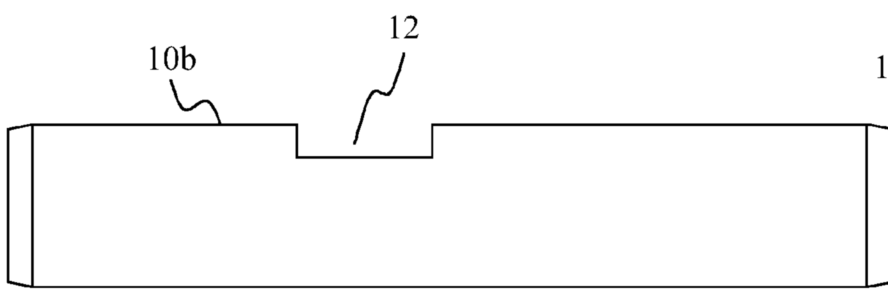


FIG. 19D

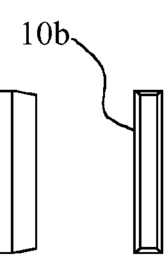
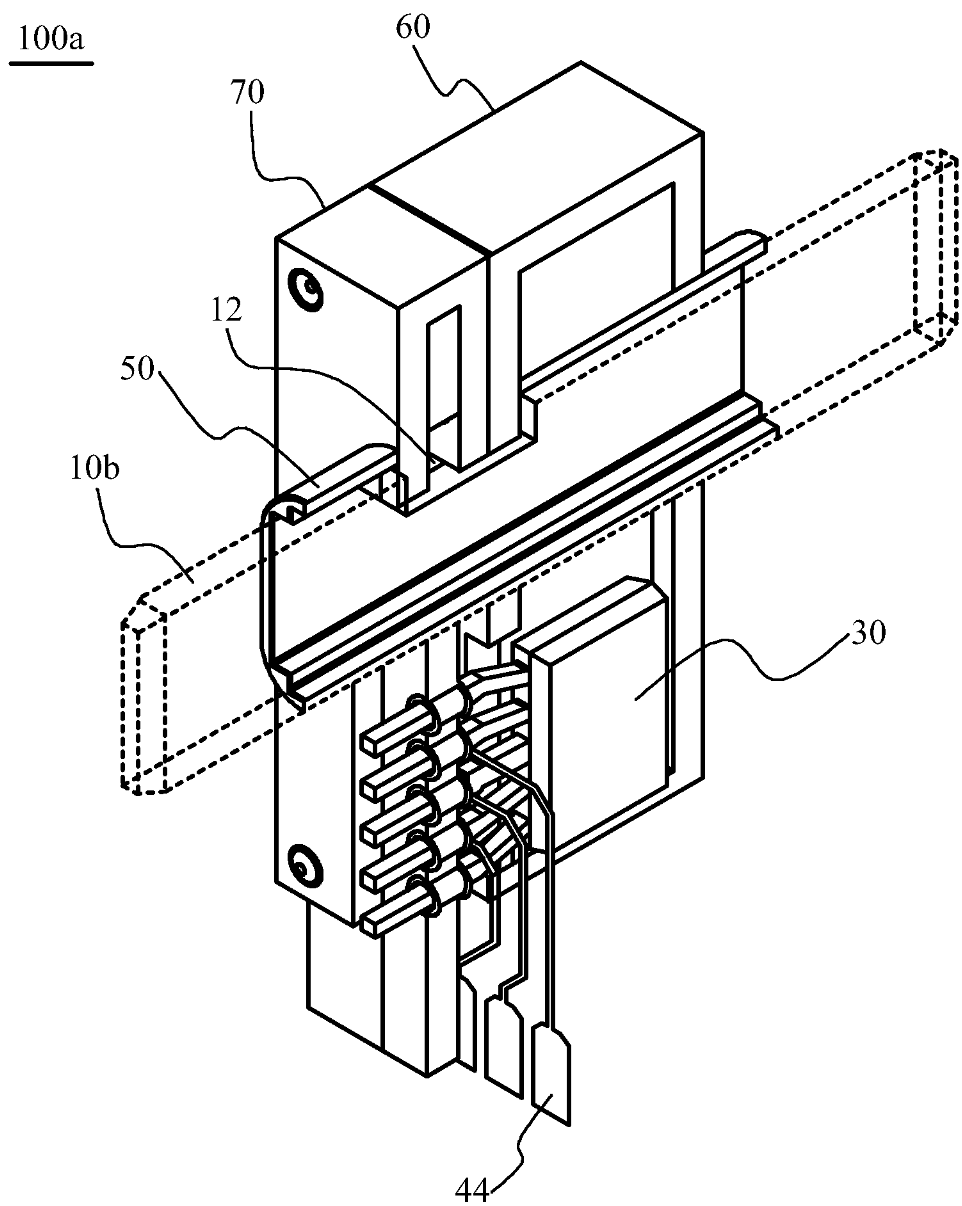


FIG. 20



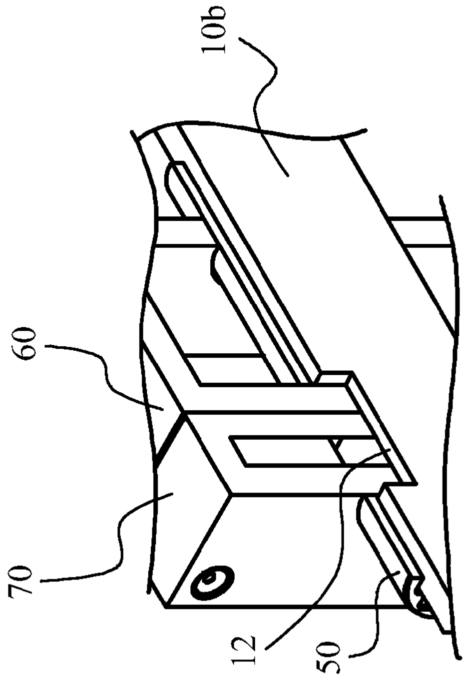


FIG. 21B

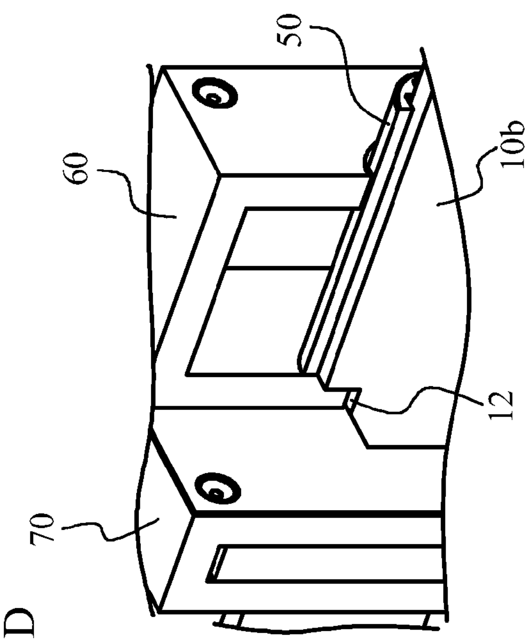


FIG. 21D

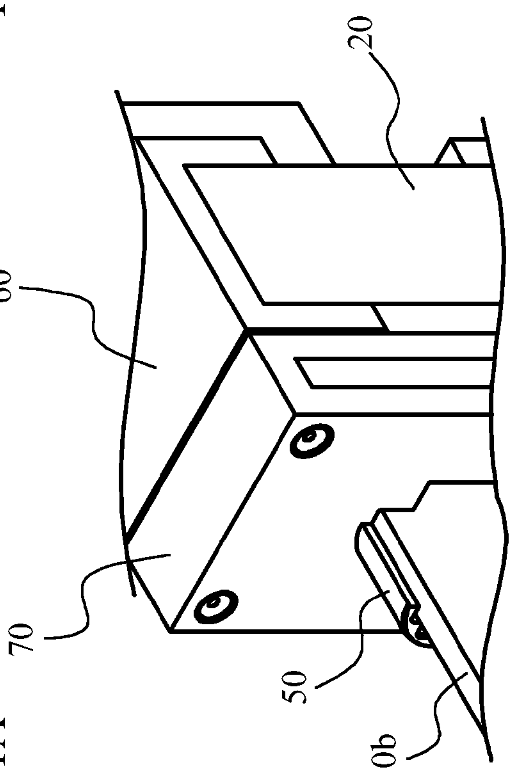


FIG. 21A

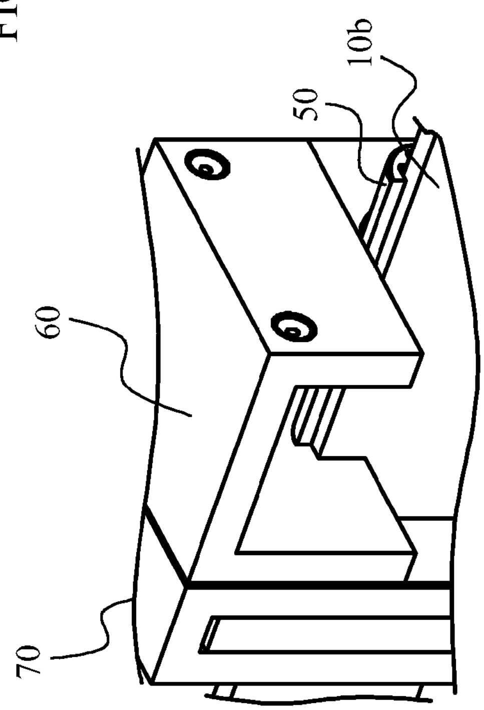


FIG. 21C

FIG. 22A

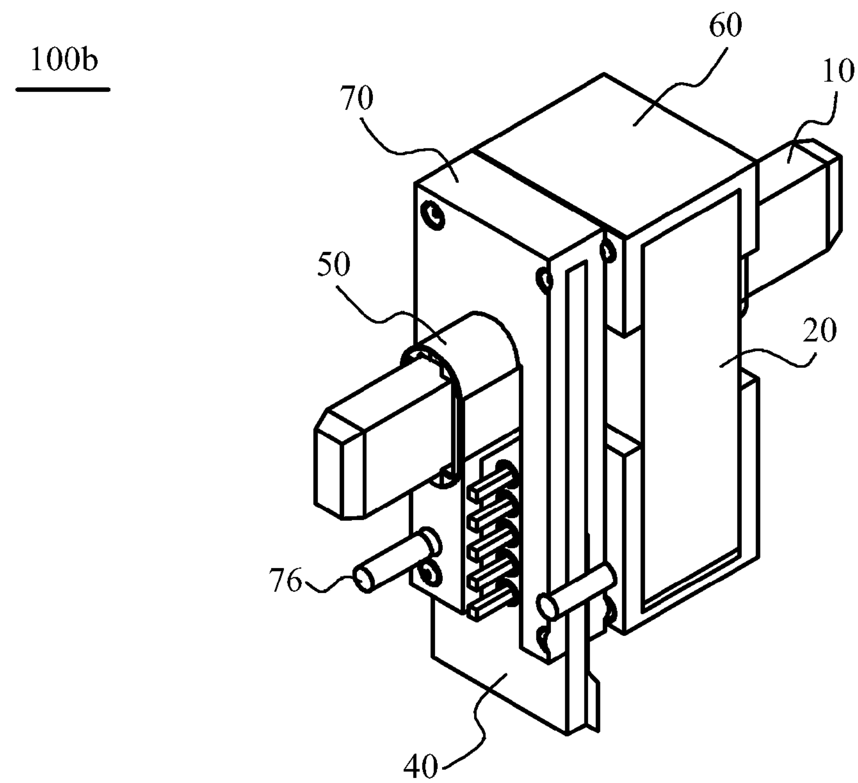


FIG. 22B

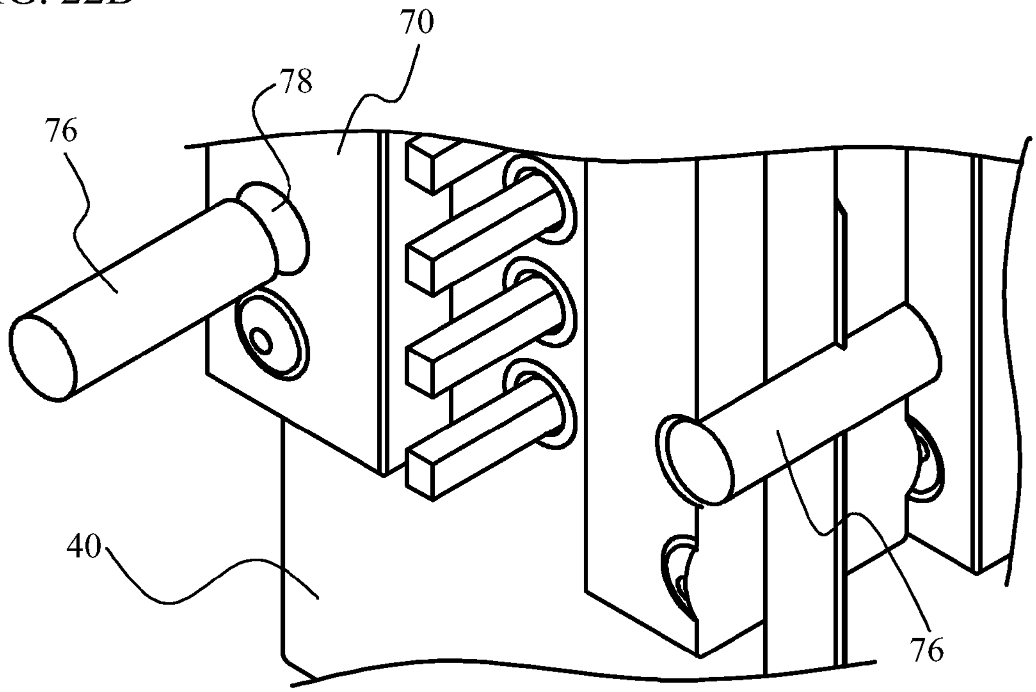


FIG. 23A

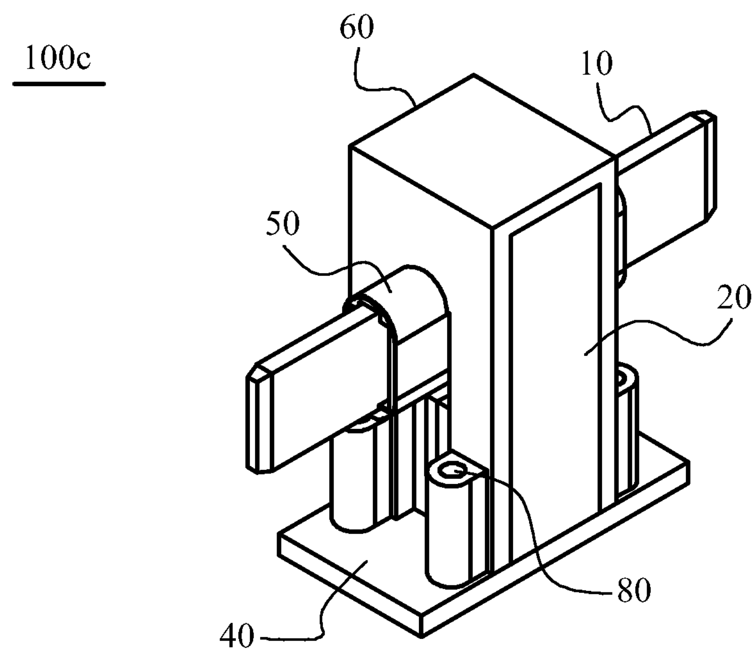


FIG. 23B

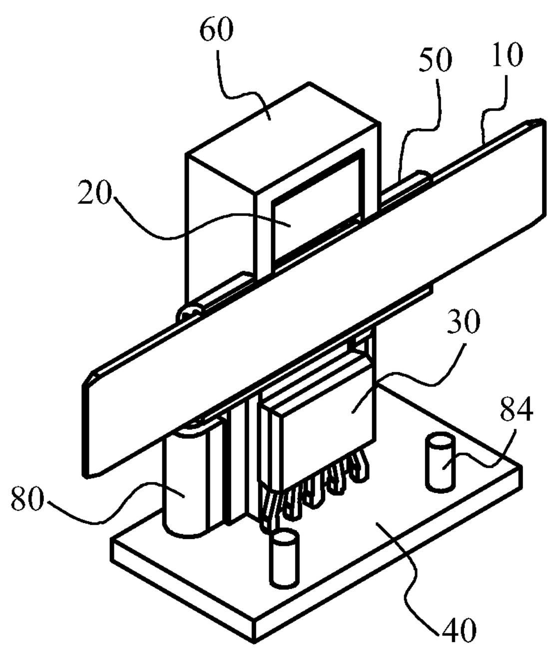


FIG. 23C

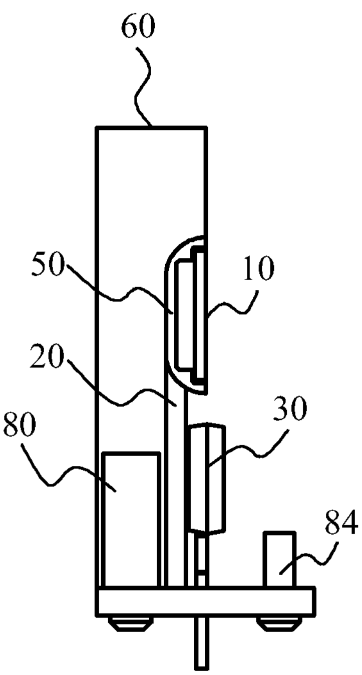


FIG. 24A

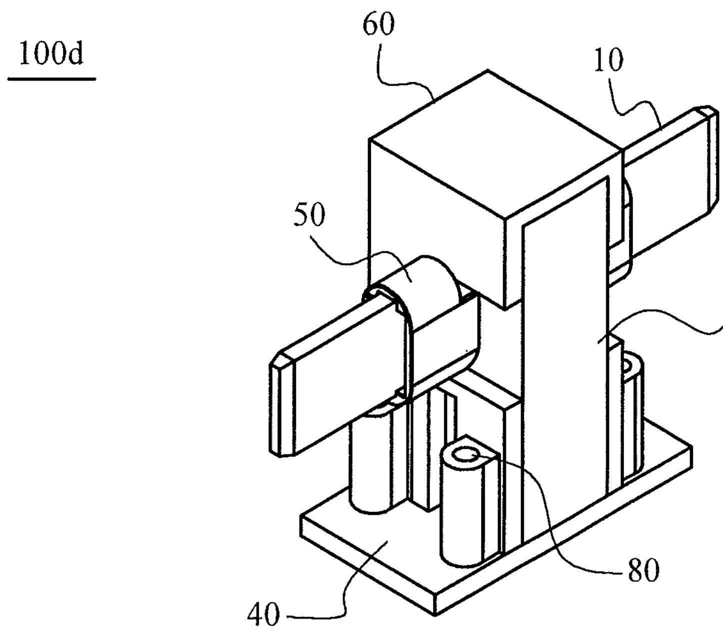


FIG. 24B

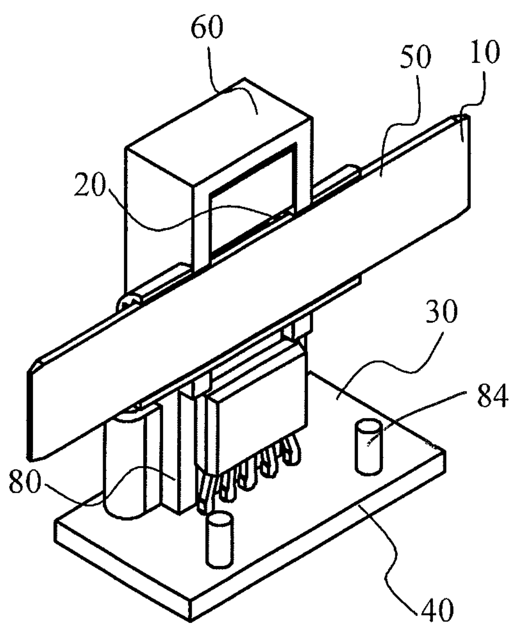


FIG. 24C

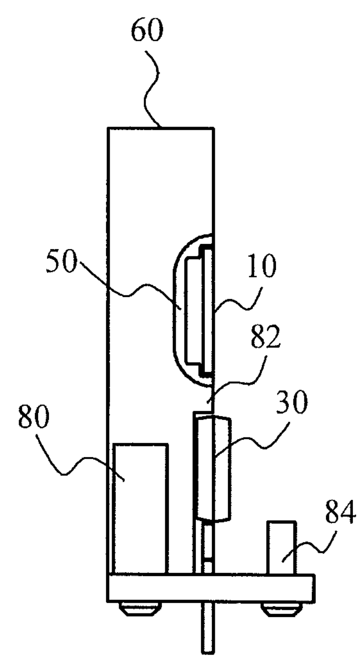


FIG. 25A

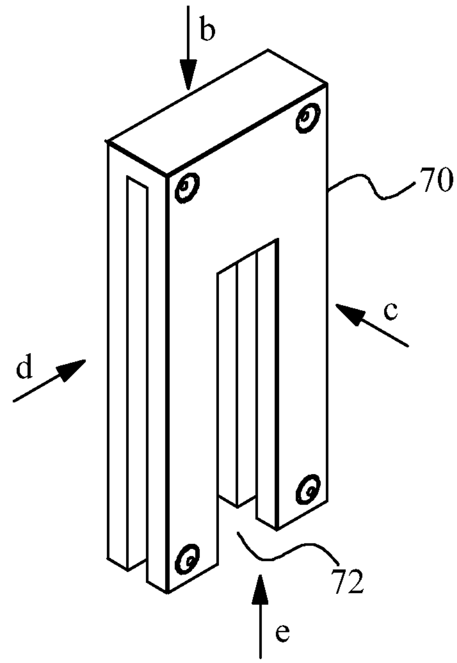


FIG. 25B

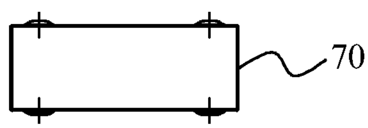


FIG. 25C

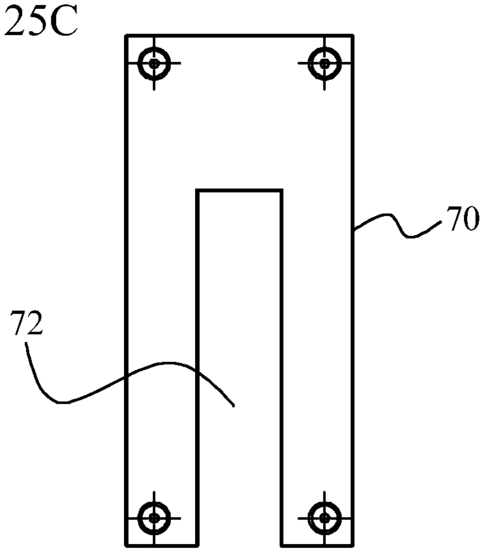


FIG. 25D

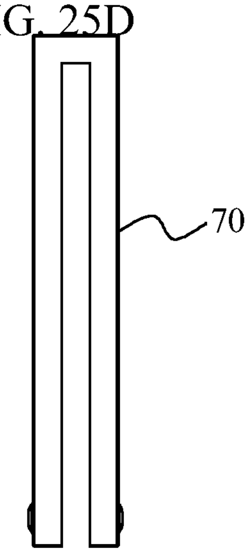
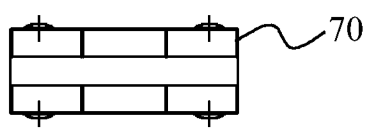


FIG. 25E



CURRENT SENSOR

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2012-206661, filed on Sep. 20, 2012, the entire contents of which are incorporated herein by reference.

FIELD

A certain aspect of the embodiments discussed herein is related to a current sensor.

BACKGROUND

There has been known a power sensor including a bus bar through which a current flows and a Hall element for measuring a magnetic field, a part of the bus bar being covered with ferrite, and the Hall element being located in a gap of the ferrite as disclosed in Japanese Patent Application Publication No. 2011-017618. Such a current sensor requires the bus bar, the ferrite, and the Hall element to have a fixed (stable) positional relationship. For example, the positional relationship may be fixed by a ferrite cover including a slit corresponding to a width of the bus bar.

Conventional current sensors have a difficulty in reducing a space because a device to which the current sensor is installed needs to have a structure for preventing a fall of the bus bar and a structure for screwing the ferrite cover.

SUMMARY

According to an aspect of the present invention, there is provided a current sensor including: a first cover that covers the current bar and includes a cutout portion formed in at least a part thereof; a magnetic substance core that covers at least parts of the current bar and the first cover and includes a gap; a magnetic field measuring element located in the gap; and a second cover that covers the magnetic substance core and the magnetic field measuring element and at least parts of the current bar and the first cover, and is located so that a side surface thereof engages with the cutout portion of the first cover.

The object and advantages of the invention will be realized and attained by the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF DRAWINGS

FIGS. **1**A and **1**B are diagrams illustrating a principle of a current sensor;

FIGS. **2**A and **2**B are diagrams illustrating a structure of a current sensor in accordance with a comparative example;

FIGS. **3**A and **3**B are diagrams illustrating a method for assembling a current sensor in accordance with a first embodiment (No. 1);

FIGS. **4**A and **4**B are diagrams illustrating the method for assembling the current sensor in accordance with the first embodiment (No. 2);

FIGS. **5**A and **5**B are diagrams illustrating the method for assembling the current sensor in accordance with the first embodiment (No. 3);

FIGS. **6**A and **6**B are diagrams illustrating the method for assembling the current sensor in accordance with the first embodiment (No. 4);

FIGS. **7**A and **7**B are diagrams illustrating the method for assembling the current sensor in accordance with the first embodiment (No. 5);

FIGS. **8**A through **8**D are diagrams illustrating a detailed structure of a bus bar;

FIGS. **9**A through **9**D are diagrams illustrating a detailed structure of a bus cover;

FIGS. **10**A through **10**D are diagrams illustrating a detailed structure of a substrate;

FIGS. **11**A through **11**G are diagrams illustrating a detailed structure of a ferrite cover;

FIGS. **12**A through **12**E are diagrams illustrating a detailed structure of a substrate cover;

FIGS. **13**A through **13**H are completion drawings of the current sensor in accordance with the first embodiment;

FIGS. **14**A through **14**D are diagrams for explaining an engaging state of components (No. 1);

FIGS. **15**A through **15**D are diagrams for explaining the engaging state of components (No. 2);

FIGS. **16**A and **16**B are diagrams comparing the current sensor of the first embodiment to the current sensor of the comparative example;

FIGS. **17**A through **17**D are diagrams illustrating a detailed structure of a bus bar having a different shape;

FIGS. **18**A through **18**H are completion drawings of a current sensor into which the bus bar with a different shape is inserted;

FIGS. **19**A through **19**D are diagrams illustrating a structure of a bus bar in accordance with a second embodiment;

FIG. **20** is a diagram illustrating a structure of a current sensor in accordance with the second embodiment;

FIGS. **21**A through **21**D are diagrams for explaining an engaging state of components;

FIGS. **22**A and **22**B are diagrams illustrating a structure of a current sensor in accordance with a third embodiment;

FIGS. **23**A through **23**C are diagrams illustrating a structure of a current sensor in accordance with a fourth embodiment;

FIGS. **24**A through **24**C are diagrams illustrating a structure of a current sensor in accordance with a variation of the fourth embodiment; and

FIGS. **25**A through **25**E are diagrams illustrating a variation of the substrate cover.

DESCRIPTION OF EMBODIMENTS

A description will first be given of a principle of a current sensor and a comparative example.

FIGS. **1**A and **1**B are diagrams illustrating a principle of current sensors in accordance with a comparative example and first through fourth embodiments. FIG. **1**A is a perspective view, and FIG. **1**B is a plan view viewing FIG. **1**A from a penetration direction of a bus bar **10**.

As illustrated in FIG. **1**A, a current sensor **100** includes the bus bar **10**, ferrite **20**, a Hall element **30**, and a substrate **40**. The bus bar **10** is an exemplary current bar through which a measured current flows, and has an elongated plate-like shape. The ferrite **20** is an exemplary magnetic substance core that enhances a magnetic field generated by a current flowing through the bus bar **10**. The Hall element **30** is an exemplary magnetic field measuring element for measuring the magnetic field enhanced by the ferrite **20**, and is fixed to the substrate **40**. The substrate **40** includes wirings (not illustrated), and the wirings are electrically coupled to the Hall element **30**. A measuring circuit (not illustrated) for measuring an output signal of the Hall element is located at ends of the wirings formed on the substrate **40**, and thus, the current flowing through the bus bar **10** can be detected based on the output.

The ferrite **20** is shaped in such a manner that side surfaces of a cuboid are hollowed out through an opposite side to be keyhole-shaped as illustrated in FIG. **1**A, for example. In the following description, a center portion (base portion of the keyhole) in the above described hollow is described as a hole portion **22**, and a slit portion heading from the hole portion **22** to a bottom surface (tip portion of the keyhole) is described as a gap **24**. As illustrated in FIG. **1**B, the bus bar **10** is located so as to penetrate the hole portion **22**, and the Hall element **30** is located in the gap **24**. The ferrite **20** has only to have a shape covering a part of the bus bar **10** in an extending direction, and the shape thereof is not limited to the tangible shape illustrated to FIG. **1**.

To perform correct measurement with the sensor, the bus bar **10**, the ferrite **20**, and the Hall element **30** preferably have a fixed positional relationship. Especially, if the bus bar **10** comes in contact with the ferrite **20**, the current flowing through the bus bar **10** causes a danger such as an electric shock and thus, they are preferably located away from each other as illustrated in FIG. **1**B.

The positional relationship can be fixed by filling up a clearance between the bus bar **10** and the ferrite **20** with a liquid such as an adhesive, but the cost for drying treatment till the liquid is solidified is high, and thus this method is not preferable. Moreover, a bus cover including a slit having the practically same width as that of the bus bar **10** may be placed over the bus bar **10** and the ferrite **20** and fixed to the substrate **40** (see FIGS. **16**A and **16**B). However, this method requires the substrate **40** to have a structure (e.g. a screw clamp, a nail, or the like) for fixing the positional relationship, and thus the positional relationship cannot be fixed with the current sensor **100** alone. Therefore, a structure presented by the comparative example (FIGS. **2**A and **2**B) will be considered.

FIGS. **2**A and **2**B are diagrams illustrating a structure of a ferrite portion of a current sensor in accordance with the comparative example. FIG. **2**A illustrates a bus cover, and FIG. **2**B is a diagram illustrating a state where the bus bar **10** with the bus cover is installed in the ferrite **20**. As illustrated in FIG. **2**A, a bus cover **50** includes a cavity corresponding to the bus bar **10** formed in the inside thereof, and has a tubular shape as a whole. As illustrated in FIG. **2**B, the bus cover **50** with the bus bar **10** penetrating therethrough is inserted into the hole portion of the ferrite **20**, and thereby, prevents contact between the ferrite **20** and the bus bar **10** and can protect a user from electrocution. This method can be achieved only by covering the bus bar **10** with the bus cover **50**, and thus the positional relationship can be fixed by the current sensor **100** alone.

However, the method in accordance with the comparative example has a possibility that the bus cover **50** falls down from the ferrite **20**. Thus, a detailed description will be given of a structure of current sensors capable of stabilizing a positional relationship among the bus bar **10**, the ferrite **20**, and the Hall element **30** in the following embodiments.

[First Embodiment]

First, a description will be given of a method for assembling the current sensor **100** in accordance with a first embodiment based on FIG. **3**A through FIG. **7**B. Then, a description will be given of a detail of each component constituting the current sensor **100** based on FIG. **8**A through FIG. **12**E, and finally a description will be given of a detailed structure of the current sensor **100** based on FIG. **14**A through FIG. **16**B.

FIG. **3**A through FIG. **7**B are perspective views illustrating the method for assembling the current sensor **100** of the first embodiment. As illustrated in FIG. **3**A, prepared is the bus cover **50** that is an exemplary first cover. Unlike the comparative example, the bus cover **50** of the first embodiment includes a cutout portion **52** in an upper surface thereof. The cutout portion **52** is formed by removing a part of the bus cover **50**, and the inside of the bus cover **50** is exposed from the cutout portion **52**. The cutout portion **52** is a structure for engaging with (hanging) side surfaces of a ferrite cover and a substrate cover as described later.

Then, the bus bar **10** is passed through the bus cover **50**, and the bus cover **50** with the bus bar **10** is passed through the hole portion **22** of the ferrite **20** as illustrated in FIG. **3**B. At this point, as the bus bar **10** is exposed to an outside from the cutout portion **52**, the bus cover **50** is located so that the cutout portion **52** is positioned outside the ferrite **20** to prevent the bus bar **10** from contacting the ferrite **20**.

Then, a ferrite cover **60** is placed to cover the ferrite **20** as illustrated in FIG. **4**A and FIG. **4**B. The ferrite cover **60** is an exemplary second cover that protects the ferrite **20**, but also has a function for fixing the positional relationship among the bus bar **10**, the bus cover **50**, and the ferrite **20** in the present embodiment. One of side surfaces of the ferrite cover **60** is an opening portion **62**, and the whole of the ferrite **20** is housed inside the ferrite cover **60** from the opening portion **62**. Further, recess portions **64** and **66** are formed in two side surfaces adjacent to the opening portion **62** (i.e. two side surfaces penetrated by the bus bar **10**), and the bus bar **10** and the bus cover **50** are placed in the recess portions **64** and **66**. In addition, a slit **68** into which the Hall element **30** is inserted in a process described later is formed in one of the side surfaces penetrated by the bus bar **10**.

Then, the substrate **40** is mounted on to the bus bar **10** as illustrated in FIG.**5**A and FIG. **5**B. A penetration hole **42** larger than the cross-section of the bus cover **50** is formed in the substrate **40**. The bus cover **50** and the bus bar **10** are passed through the penetration hole **42**, and thereby the substrate **40** is hung on the cutout portion **52** of the bus cover **50** (i.e. bus bar **10**) and tentatively positioned. Moreover, wirings **44** are formed on the substrate **40**, and the Hall element **30** electrically coupled to the wirings **44** is fixed to the substrate **40**. The Hall element **30** protrudes from the surface of the substrate **40**, and is inserted from the slit **68** of the ferrite cover **60** into the inside and positioned in the gap **24** of the ferrite **20** when the substrate **40** is hung on the bus bar **10**.

Then as illustrated in FIGS. **6**A and **6**B, a substrate cover **70** is placed to cover the substrate **40**. Unlike the ferrite cover **60**, the substrate cover **70** is mounted on to the substrate **40** from an upper direction (direction counter to gravity). At this point, a side surface of the substrate cover **70** engages with the cutout portion **52** of the bus cover **50**. Moreover, side surfaces of the ferrite cover **60** and the substrate cover **70** contact each other and a raised structure and a recess structure formed in the side surfaces engage with each other, and thereby, the ferrite cover **60** and the substrate cover **70** are fixed to each other. This will be described in detail later.

FIG. **7**A and FIG. **7**B are perspective views of the current sensor **100** to which the substrate cover **70** is mounted on. The cutout portion **52** of the bus cover **50** has a length (length in a direction in which the bus bar **10** extends) configured to be equal to the sum of the overall thickness of the substrate cover **70** and the thickness of one of the side surfaces of the ferrite cover **60**. This configuration allows the ferrite cover **60** and the substrate cover **70** to be engaged with and fixed to the cutout portion **52** of the bus cover **50**.

FIGS. **8**A through **8**D are diagrams illustrating a detailed structure of the bus bar **10**. FIG. **8**A is a perspective view, and FIGS. **8**B through **8**D are plan views viewed from b through d-directions in FIG. **8**A respectively. As illustrated, the bus bar **10** has an elongated plate-like shape in one direction (d-direction). As illustrated in FIGS. **8**B through **8**D, both end portions of the bus bar **10** are inclined so that the cross-sections thereof decrease toward the outside. The structure of the bus bar **10** is not limited to the present embodiment, and may be any that allows a measured current to flow therethrough.

FIGS. **9**A through **9**D are diagrams illustrating a detailed structure of the bus cover **50**. FIG. **9**A is a perspective view, and FIGS. **9**B through **9**D are plan views viewed from b through d-directions in FIG. **9**A respectively. As illustrated in FIG. **9**B, an upper portion of the bus cover **50** is removed to the cutout portion **52**, and the inside of the bus cover **50** is exposed, but the structure of the cutout portion **52** is not limited to the present embodiment and may be any that can engage with the ferrite cover **60** and the substrate cover **70**. In addition, as illustrated in FIG. **9**D, the cavity formed in the bus cover **50** into which the bus bar **10** is inserted has a nearly cross shape formed by crossing two rectangles with different shapes at centers thereof. This configuration is for allowing the bus bars **10** with different sizes to be inserted, and this will be described in detail later.

FIG. **10** is a diagram illustrating a detailed structure of the substrate **40**. FIG. **10**A is a perspective view, and FIGS. **10**B through **10**D are plan views viewed from b through d-directions in FIG. **10**A respectively. FIGS. **10**A through **10**D omit the illustration of the Hall element **30** and the wirings **44**. As illustrated in FIGS. **10**A and **10**C, the substrate **40** includes: the penetration hole **42** into which the bus bar **10** and the bus cover **50** are inserted; and pin holes **46** to which pins of the Hall element **30** are inserted. The Hall element **30** is fixed to the substrate **40** by inserting the pins to the pin holes **46** and penetrating them through the opposite side.

FIGS. **11**A through **11**G are diagrams illustrating a detailed structure of the ferrite cover **60**. FIG. **11**A and FIG. **11**B are perspective views viewed from different directions, and FIG. **11**C through FIG. **11**D are plan views viewed from c through g-directions in the perspective views respectively. As illustrated, the side surface in the d-direction of the ferrite cover **60** is the opening portion **62** from which the ferrite **20** is inserted. The side surfaces in the e-direction and the g-direction of the ferrite cover **60** include the recess portions **64** and **66** communicating with the opening portion **62**, respectively. The recess portion **64** formed in the side surface in the g-direction engages with the cutout portion **52** of the bus cover **50**, and thus is smaller than the recess portion **66** formed in the side surface in the e-direction, and a corner portion thereof is not rounded so as to make the engagement easy. In contrast, the recess portion formed in the side surface in the e-direction does not engage with the cutout portion **52** of the bus cover **50**, and thus is larger than the recess portion **64** formed in the side surface in the g-direction, and corner portions are rounded so as to be along the chassis of the bus cover **50**. These configurations are illustrated in FIG. **11**D, FIG. **11**E, and FIG. **11**G.

Moreover, recess and raised structures that engage with the substrate cover **70** are formed in the ferrite cover **60**. The present embodiment forms recess structures **61** at an upper side (side closer to the bus bar **10**) and raised structures **63** at a lower side, but does not intend to suggest any limitation. Moreover, the side surface in the f-direction of the ferrite cover **60** is an opening portion as with the side surface in the d-direction in the present embodiment, but the ferrite cover **60** has only to cover the ferrite **20** from at least the d-direction or the f-direction, and the other opening portion may be closed.

FIGS. **12**A through **12**E are diagrams illustrating a detailed structure of the substrate cover **70**. FIG. **12**A is a perspective view, and FIGS. **12**B through **12**E are plan views viewed from b through e-directions in FIG. **12**A respectively. As illustrated, two side surfaces of the substrate cover **70** (c-direction and counter direction thereof) include recess portions **72** formed therein so as to open toward the bottom side (e-direction). A cross-sectional shape of the base portion of the recess portion **72** is a step-like shape as indicated by reference numeral **74** in FIG. **12**C. This is for engaging with a multilevel structure formed by the bus bar **10** exposed from the cutout portion **52** and the chassis of the bus cover **50** in the cutout portion **52** of the bus cover **50**. This structure allows the substrate cover **70** to stably support the bus cover **50**.

In addition, recess and raised structures for engaging with the ferrite cover **60** are formed in the substrate cover **70**. The present embodiment forms raised structures **75** at an upper side (side closer to the bus bar **10**) so as to engage with the ferrite cover **60** of FIGS. **11**A through **11**G, and forms recess structures **77** at a lower side, but does not intend to suggest any limitation.

FIGS. **13**A through **13**H are diagrams illustrating a detailed structure of a completion state of the current sensor **100**. FIG. **13**A is an external perspective view, and FIG. **13**B is a perspective view in which the current sensor **100** is halved lengthwise. FIGS. **13**C through **13**H are plan views viewed from c through h-direction in FIG. **13**A respectively. As illustrated, the bus bar **10** is inserted into the inside of the bus cover **50** to be positioned with respect to the ferrite **20**. Especially, in the inside of the ferrite cover **60**, the bus cover **50** separates the bus bar **10** from the ferrite **20**, and prevents contact therebetween. Moreover, the Hall element **30** electrically coupled to the substrate **40** is inserted from the slit **68** of the ferrite cover **60** into the gap **24** of the ferrite **20**, and positioned with respect to the ferrite **20**. An engaging state of the bus cover **50**, the ferrite cover **60**, and the substrate cover **70** will be described in detail in FIG. **14**A through FIG. **15**D.

FIGS. **14**A through **14**D are diagrams for explaining an engaging state of components in the current sensor **100** (No. 1), and illustrate the current sensor **100** halved lengthwise as with FIG. **13**B. As illustrated in FIG. **14**A, a first outer periphery of the cutout portion **52** of the bus cover **50** engages with the side surface of the substrate cover **70**, and a second outer periphery engages with the side surface of the ferrite cover **60**. The bus bar **10** inserted into the bus cover **50** fails to engage with the substrate cover **70** and the ferrite cover **60**, and thus can be freely moved along its extending direction (insertion direction) as illustrated in FIGS. **14**B through **14**D. Therefore, in an assembly process, the components except the bus bar **10** are assembled first, and the bus bar **10** can be inserted lastly.

FIGS. **15**A through **15**D are diagrams for explaining the engaging state of the components in the current sensor **100** (No. 2), and enlarge an engaging part illustrated in FIGS. **14**A through **14**D. As illustrated in FIG. **15**A, the step-like shape of the recess portion **72** of the substrate cover **70** engages with the multilevel structure of the cutout portion **52** formed by the bus bar **10** and the bus cover **50**. In addition, as illustrated in FIGS. **15**B and **15**D, the side surface of the ferrite cover **60** located on the opposite side to the substrate cover **70** does not engage with the cutout portion **52** of the bus cover **50**, and contacts the bus cover **50** along the roundness of the bus cover **50**.

As described above, the current sensor **100** of the first embodiment engages the ferrite cover **60** with the cutout portion **52** of the bus cover **50** to fix the ferrite cover **60** and the bus cover **50**. In addition, the bus bar **10** and the ferrite **20** are positioned by the ferrite cover **60** and the bus cover **50**. Therefore, the positional relationship among the components of the current sensor can be stabilized.

Moreover, the current sensor **100** of the first embodiment places the substrate **40** on which the Hall element **30** is mounted to be aligned with the ferrite **20** from the lateral direction of the ferrite cover **60**, and positions and fixes the substrate **40** by the substrate cover **70**. This can reduce the space compared to a case where the bottom portion of the ferrite **20** is fixed and screwed on the substrate.

FIGS. **16**A and **16**B are perspective views comparing the current sensors of the first embodiment and a comparative example (different from the one illustrated in FIG. **2**). As illustrated, the first embodiment (FIG. **16**A) reduces an installation space for the current sensor **100** compared to the current sensor **110** of the comparative example (FIG. **16**B) because a structure supporting a fall of the bus bar **10** and a screw clamp receiving a screw **112** are unnecessary. More specifically, the installation area can be reduced by approximately 60%.

Further, the current sensor **100** of the first embodiment is configured so that only one side surface of the two side surfaces of the ferrite cover **60** penetrated by the bus bar **10** engages with the cutout portion **52** of the bus cover **50**. This configuration allows the bus cover **50** to separate the ferrite **20** from the bus bar **10** in the inside of the ferrite cover **60**, and prevent contact between them.

In addition, the current sensor of the first embodiment is configured so that the cross sectional shape of the bus cover **50** is a nearly cross shape formed by crossing two different rectangles at their centers, and thus can accommodate two different bus bars **10**. This configuration enables to quickly accommodate the specifications of the various devices because the bus bar **10** can be easily changed when the bus bar **10** is selected from several types thereof in accordance with circumstances.

FIGS. **17**A through **17**D are diagrams illustrating a detailed structure of a bus bar with a different size. FIG. **17**A is a perspective view, and FIGS. **17**B through **17**D are plan views viewed from b through d-direction in FIG. **17**A. The long side of the rectangle in the cross section is short and the short side is long compared to the bus bar illustrated in FIGS. **8**A through **8**H. As a whole, the cross section area is large (bold) and a large amount of current can flow compared to the bus bar in FIGS. **8**A through **8**H.

FIGS. **18**A through **18**H are diagrams illustrating a state where a bus bar **10***a* in FIGS. **17**A through **17**D is inserted into the current sensor **100**, and correspond to FIGS. **13**A through **13**H. FIG. **18**A is an external perspective view, FIG. **18**B is a perspective view in which the current sensor **100** is halved lengthwise. FIGS. **18**C through **18**H are plan views viewed from c through h-direction in FIG. **18**A respectively. The same bus cover **50** is used in FIGS. **13**A through **13**H and FIGS. **18**A through **18**H, and only the shape of the bus bar is different, but the positional relationship between the bus bar **10***a* and the ferrite **20** is stable as with the FIGS. **13**A through **13**H.

Moreover, the current sensor **100** of the first embodiment forms a recess structure and a raised structure engaging with each other in the side surfaces of the ferrite cover **60** and the substrate cover **70**. This configuration allows the ferrite cover **60** to directly engage with the substrate cover **70**, and can achieve further stabilization. The tangible structure of the recess and raised structures is not limited to the one described in the first embodiment. For example, the recess structure and the raised structure may be formed in any of the ferrite cover **60** and the substrate cover **70**, or may be formed in both. The number of and the formation position of the recess structure and the raised structure are not limited either.

[Second Embodiment]

A second embodiment engages not only a bus cover but also a bus bar with a ferrite cover.

FIGS. **19**A through **19**D are diagrams illustrating a detailed structure of a bus bar **10***b* in accordance with the second embodiment. FIG. **19**A is a perspective view, and FIGS. **19**B through **19**D are plan views viewed from b through d-direction in FIG. **19**A. As illustrated in FIG. **19**A and FIG. **19**C, an upper edge (edge in the b-direction) of the bus bar **10***b* includes a recess portion **12** formed in a position corresponding to the cutout portion **52** of the bus cover **50**. A shape of the recess portion **12** may be any that can engage with ferrite cover **60** and the substrate cover **70**, and is not limited to the tangible structure illustrated in FIGS. **19**A through **19**D.

FIG. **20** is a completion drawing of a current sensor **100***a* in accordance with the second embodiment, and is a perspective view in which the current sensor **100***a* is halved lengthwise. An external view of the current sensor **100***a* is the same as that of the first embodiment, and the illustration thereof is omitted (the same as FIG. **18**A and FIGS. **18**C through **18**H). As illustrated in FIG. **20**, the substrate cover **70** and the ferrite cover **60** engage with the cutout portion **52** of the bus cover **50** and the recess portion **12** of the bus bar **10***b*. Thereby, unlike FIGS. **14**B through **14**D of the first embodiment, the bus bar **10***b* cannot move in the insertion direction.

FIGS. **21**A through **21**D are diagrams for explaining an engaging state of components in the current sensor **100***a*, and enlarges the engaging part illustrated in FIG. **20**. As illustrated in FIGS. **21**A and **21**B, the side surface at an inner side (substrate cover **70** side) of the ferrite cover **60** engages with the cutout portion **52** of the bus cover **50** and the recess portion **12** of the bus bar **10***b*. Moreover, as illustrated in FIGS. **21**C and **21**D, the side surface at an outer side (opposite side to the substrate cover **70**) of the ferrite cover **60** does not engage with the cutout portion **52** of the bus cover **50**, and contacts the bus cover **50** along the roundness of the outer ward of the bus cover **50**.

as described above, the current sensor **100***a* of the second embodiment engages the ferrite cover **60** with the recess portion **12** located in the bus bar **10***b* to fix the position of the bus bar **10***b*, and thereby, can achieve futher stabilization.

[Third Embodiment]

A third embodiment achieves further fixation of the substrate cover **70** by pins.

FIG. **22**A is an external perspective view (partly cross-sectional view) of a current sensor **100***b* of the third embodiment, and FIG. **22**B is an enlarged view of a pin insertion area. As illustrated in FIG. **22**B, in the current sensor **100***b*, penetration holes through which pins **76** penetrate are formed in the substrate **40** and the substrate cover **70** (numeral reference **78** represents the penetration holes of the substrate cover **70**). The pins **76** penetrating through the penetration holes for fixation require detachment of the pins **76** when the current sensor **100***b* is deconstructed, and thus the substrate **40** and the substrate cover **70** are further stably fixed. Instead of the pins **76**, a member such as a screw may be used. The member may be any that can fix the substrate **40** and the substrate cover **70** through the penetration holes formed in them, and is not limited to the present embodiment.

[Fourth Embodiment]

A fourth embodiment mounts the substrate **40** on to a bottom of the ferrite **20**.

FIGS. **23**A through **23**C are diagrams illustrating a structure of a current sensor **100***c* in accordance with the fourth embodiment. FIG. **23**A is an external perspective view, FIG. **23**B is a cross-sectional view in which the current sensor **100***c* is halved lengthwise, and FIG. **23**C is a plan view that views FIG. **23**B from the insertion direction of the bus bar **10**. As illustrated, the Hall element **30** is fixed to the substrate **40** so as to protrude upward, the ferrite **20** and the ferrite cover **60** are placed from the upper direction of the substrate **40**, and thereby, the Hall element **30** is inserted into the gap **24** of the ferrite **20**. As illustrated in FIGS. **23**B and **23**C, the ferrite cover **60** includes a reception portion **80** into which a screw can be inserted from a bottom, and a pin or screw **84** is caused to penetrate from the back side of the substrate **40** to be inserted into the reception portion **80** of the ferrite cover **60**, and thereby the ferrite cover **60** and the substrate **40** are fixed to each other.

Unlike the first through third embodiments, the current sensor **100***c* of the fourth embodiment does not include the substrate cover **70**, and the ferrite cover **60** engages with the cutout portion **52** of the bus cover **50** alone. Therefore, as illustrated in FIG. **23**B, two sides surface of the ferrite cover **60** penetrated by the bus bar **10** engage with the cutout portion **52** of the bus cover **50**, and thereby the bus cover **50** and the ferrite cover **60** are positioned with respect to each other. The ferrite cover **60** is inserted from the upper direction of the ferrite **20**, and thus the ferrite cover **60** does not have a structure supporting the bus cover **50**, and the bus cover **50** is directly supported by the ferrite **20** as illustrated in FIG. **23**C.

As described above, even the current sensor **100***c* of the fourth embodiment that does not use the substrate cover **70** can also engage the ferrite cover **60** with the bus cover **50** using the cutout portion **52** of the bus cover **50** as the first through third embodiments do.

FIGS. **24**A through **24**C are diagrams illustrating a structure of the current sensor **100***c* in accordance with a variation of the fourth embodiment. FIG. **24**A is an external perspective view, FIG. **24**B is a cross- sectional view in which the current sensor **100***c* is halved lengthwise, and FIG. **24**C is a plan view that views FIG. **24**B from the insertion direction of the bus bar **10**. Unlike FIGS. **23**A through **23**C, the recess portion **64** formed in the side surface of the ferrite cover **60** communicates with the opening portion **62** in the side surface of the ferrite cover **60**, and the ferrite cover **60** can be mounted on to the ferrite **20** from a horizontal direction. This configuration allows support the bus cover **50** by a support portion **82** of the ferrite cover **60** from a direction of gravity. The ferrite **20** breaks easily, but this configuration can prevent damage to the ferrite **20**.

The first through fourth embodiments configure a recess portion in the substrate cover **70** to have a step-like shape as illustrated in FIG. **12**C, but the configuration of the recess portion is not limited to the embodiments, and may be any that can engage with the cutout portion **52** of the bus cover **50**. For example, as illustrated in FIGS. **25**A through **25**E, a substrate cover of which the shape of the base of the recess portion is a simple rectangle may be used.

All examples and conditional language recited herein are intended for pedagogical purposes to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although the embodiments of the present invention have been described in detail, it should be understood that the various change, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A current sensor comprising:
- a current bar through which a current flows;
- a first cover that includes an opening into which the current bar is contactably inserted and includes a cutout portion formed in at least a part thereof;
- a magnetic substance core that covers a part of the first cover into which the current bar is inserted and includes a gap;
- a magnetic field measuring element located in the gap; and
- a second cover that covers the magnetic substance core, and includes a side surface engaging with the cutout portion of the first cover.

2. The current sensor according to claim **1**, further comprising:
- a substrate to which the magnetic field measuring element is fixed, and in which a penetration hole that is penetrated by the current bar is formed; and
- a third cover that covers the substrate and includes a side surface engaging with the cutout portion of the first cover.

3. The current sensor according to claim **2**, wherein one side surface of the second cover and one side surface of the third cover contact with each other.

4. The current sensor according to claim **3**, wherein
- a raised portion is formed in at least one of the side surfaces of the second cover and the third cover contacting with each other, and
- a recess portion is formed in at least the other of the side surfaces contacting with each other.

5. The current sensor according to claim **2**, further comprising:
- a fixing member that penetrates the substrate and the third cover.

6. The current sensor according to claim **1**, wherein
- a cross section sectional shape of the opening in the first cover is stepped so as to accommodate current bars with different sizes.

7. The current sensor according to claim **1**, wherein
- the current bar includes a recess portion formed in a position corresponding to the cutout portion of the first cover, and
- a side surface of the second cover engages with the recess portion.

8. The current sensor according to claim **1**, wherein
- the second cover includes a support portion that supports the first cover from a direction of gravity.

9. The current sensor according to claim **2**, wherein
- a slit is formed in a side surface of the second cover, and
- the magnetic field measuring element is inserted into the gap of the magnetic substance core from the slit.

10. A current sensor comprising:
- a current bar through which a current flows;
- a first cover that covers the current bar and includes a cutout portion formed in at least a part thereof;
- a magnetic substance core that covers at least parts of the current bar and the first cover and includes a gap;
- a magnetic field measuring element located in the gap;
- a second cover that covers the magnetic substance core and the magnetic field measuring element and at least parts of the current bar and the first cover, and is located so that

a side surface of the second cover engages with the cutout portion of the first cover;

a substrate to which the magnetic field measuring element is fixed, and in which a penetration hole that is penetrated by the current bar is formed; and

a third cover that fixes the substrate to the first cover, wherein

the magnetic field measuring element is inserted into the gap of the magnetic substance core from a slit formed in a side surface of the second cover, and

the third cover covers the substrate and at least parts of the current bar and the first cover, and is located so that a side surface of the third cover engages with the cutout portion of the first cover.

11. The current sensor according to claim **10**, wherein

the second cover has a first side surface that is one of two side surfaces penetrated by the current bar and engages with the cutout portion of the first cover;

the third cover has a first side surface that is one of two side surfaces penetrated by the current bar and engages with the cutout portion of the first cover, and

second side surfaces, out of the two side surfaces of the second cover and the third cover, that fail to engage with the cutout portion, and that contact with each other.

12. The current sensor according to claim **11**, wherein

a raised portion is formed in at least one of the second side surfaces contacting with each other in the second cover and the third cover, and

a recess portion is formed in at least the other of the second surfaces.

13. The current sensor according to claim **10**, further comprising:

a fixing member that penetrates the substrate and the third cover.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,250,273 B2
APPLICATION NO. : 13/933796
DATED : February 2, 2016
INVENTOR(S) : Naoyuki Nagao

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the claims

Column 10, Line 42, Claim 6
Delete “cross section sectional” and insert -- cross-sectional --, therefor.

Signed and Sealed this
Tenth Day of May, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office